

Multiagent Systems using Small World Networks

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ABSTRACT

In a graph with a "small world" topology, nodes are highly clustered yet the distance between any two nodes is almost as short as a completely random graph. Such an approach for multiagent communication can dramatically increase inter-agent communication—particularly in systems where the number of agents is very large.

INTRODUCTION

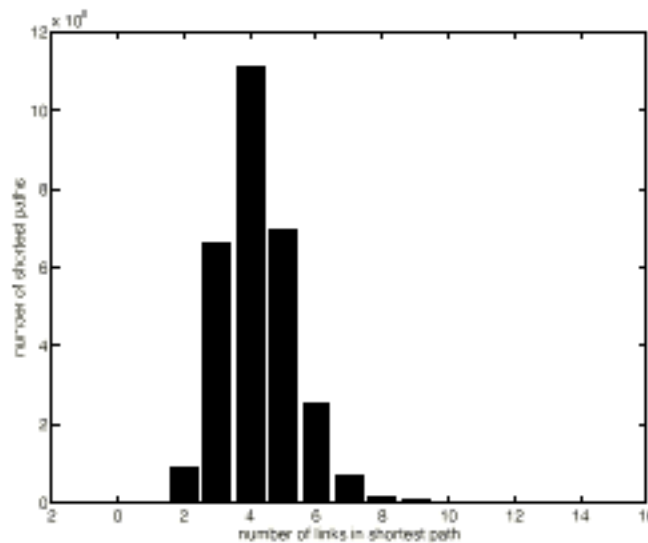
Small world systems are found in many natural and artificial systems. For example, they have been identified in the collaboration graph of film actors, the citation graph of famous Hungarian mathematician Paul Erdős, the electric grid of the western United States [1], and the world-wide web [2]. In John Guare's play *Six Degrees of Separation*, one of the characters proclaims that "Everybody on this planet is separated by only six other people." "Six degrees" is now firmly embedded in folklore, embracing everyone from Kevin Bacon to Monica Lewinsky [3]. As a result, the idea can be hard to take seriously. And yet, it seems that social systems really are constructed in a manner that bestows a small "degree of separation."

WHAT ARE SMALL WORLD SYSTEMS?

Small world systems are highly clustered networks, yet the maximum distance between any two randomly chosen nodes is short. By comparison, random graphs are not clustered and have short distances, while regular lattices are clustered and have long distances. Watts [1] has demonstrated that a regular lattice can be transformed into a small world network by making a very small fraction (0.1% to 1.0%) of the connections random.

Changing a regular lattice to a small world topology can strongly affect the properties for the graph. For example, a small fraction of random links added to a social network of agents such as people will dramatically increase the speed at

which rumors or diseases spread. In multiagent systems, such small changes could decrease the time required to search or communicate among agents—as well as the spread of viruses among agents. Even a single search bot using a small world network such as the World Wide Web would benefit. One study [2] involving approximately 65,000 websites determined that the average path length was 4.228 nodes and a maximum of 10 nodes. The histogram below illustrates this study's results. It depicts the number of occurrences at each degree of separation.



In the total World Wide Web, it is estimated that there are 1.5 billion web pages, yet the maximum distance between any two is estimated at 19 pages. It is reasonable to expect similar results in large multiagent social systems.

SOME IMPLICATIONS

Small amounts of random rewiring can achieve much the same result as:

- large amounts of rewiring
- a massive addition of nonrandom links

Furthermore, not just any random rewiring will do. The key is employing a

- small fraction of very long range (global) connections,
- while most local connections remain.

Implication #1

It costs more in energy to build a long range connection than a short range connection. If you're going to have lot of connections, it's better to make most of them short. For example, if an organism is expending too much energy building long range extensions, it's not going to survive. On the other hand, if it doesn't

build any, then its performance decreases. The same analogy applies to agents: it is too costly to create associations with only random agents.

Implication #2

We're not always in a position to design these networks from the ground up. Yet, dramatic results can be achieved with only small perturbations. It doesn't matter whether you start with a hierarchical structure or a ring. In short, the network is sensitive to small changes.

CONCLUSION

Briefly, small-world networks are

- a tuned interpolation between perfect order and perfect randomness, where
- you can move from anywhere to anywhere else using a finite number of links.

Small world networks are a possible answer to situations where you want to have

- efficient transmission (have a small characteristic path length)
- local clustering (which enables us to have cohesive action)
- no individual that is overwhelmed with input (have a small k)
- decentralized network (making it more robust)

As such, small world networks have many uses for industrial applications:

- Web-based searches
- Agent communication
- Information processing in irregular networks
- Design of telecommunication networks (e.g., Internet and cellular phone networks)
- Cooperative behavior in large organizations (both human and software agent cooperation)
- Formation and spread of computer viruses and software updates
- Improved search algorithms for optimal strategies to complex problems

REFERENCES

- [1] Watts, Duncan J., *Small Worlds: The Dynamics of Networks between Order and Randomness*, Princeton University Press, Princeton, NJ, 1999.
- [2] Adamic, Lada, "The Small World Web," paper from Xerox Parc Research Center, www.parc.xerox.com/istl/groups/iea/smallworldpaper.html, 1999.
- [3] Kirby, D., and Sahry, P., "Six Degrees of Monica," *New York Times*, 21 October 1998, Op ed. Page.